Spectroscopic analysis of DA white dwarfs from the McCook & Sion catalog[1]

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Abstract. For some years now, we have been gathering optical spectra of DA white dwarfs in an effort to study and define the empirical ZZ Ceti instability strip. However, we have recently expanded this survey to include all the DA white dwarfs in the McCook & Sion catalog down to a limiting visual magnitude of V=17.5. We present here a spectroscopic analysis of over 1000 DA white dwarfs from this ongoing survey. We have several specific areas of interest most notably the hot DAO white dwarfs, the ZZ Ceti instability strip, and the DA+dM binary systems. Furthermore, we present a comparison of the ensemble properties of our sample with those of other large surveys of DA white dwarfs, paying particular attention to the distribution of mass as a function of effective temperature.

1. Introduction

Although the Sloan Digital Sky Survey (SDSS) has unearthed thousands of new white dwarfs, it is our belief that there is a significantly brighter sample of white dwarfs whose scientific potential has never truly been exploited. With this in mind, we have undertaken a systematic survey of DA white dwarfs based, in large part, on the last published version of the catalog of spectroscopically identified white dwarfs of McCook & Sion (1999). We will first describe our survey and how it compares to other large surveys of DA white dwarfs and examine some of the ensemble properties of our current sample. We will then take a closer look at a few choice subsamples of objects. In particular, we will look at the DAO white dwarfs, the ZZ Ceti instability strip, and the DA+dM binaries. Finally, we will look at one specific object, CBS 229, which we believe to be a binary system with a magnetic component.

2. Survey Overview

Over the last few years, we have been obtaining optical spectra for DA white dwarfs near the ZZ Ceti instability in an effort to constrain its empirical boundaries. More recently, we expanded this observational survey to include all the DA white dwarfs from the McCook & Sion catalog down to a limiting visual magnitude of V=17.5. Many of these stars have never been analyzed with modern CCD spectroscopy and the only information available is a spectral classification, which

[1] Based on observations made with ESO Telescopes at the La Silla or Paranal Observatories under program ID 078.D-0824(A) and with the Las Campanas 2.5 m Irénée du Pont telescope.

is often erroneous. The bulk of this project has been conducted using Steward Observatory's 2.3 m telescope at Kitt Peak. However, we were also able to obtain time on the ESO 3.6 m telescope at La Silla (Chile) as well as Carnegie Observatories' 2.5 m du Pont telescope at Las Campanas (Chile), allowing us to extend our survey into the southern hemisphere.

How does our work compare to other large surveys of DA white dwarfs? The SPY project (Koester et al. 2001), which obtained high resolution spectra for several hundred white dwarfs, had a limiting magnitude of $V = 16.5$ and was conducted in the southern hemisphere at the VLT. There is actually quite a large overlap with our own sample of stars. Indeed, close to 80% of the stars surveyed in SPY are included in this work. In contrast, we have only a very small overlap with the SDSS (see Figure 1) owing to the fact that the majority of their objects are quite faint due to the nature of the SDSS itself. The faintness of the objects in the SDSS also limits the quality of their spectra since a single exposure time is set for all the objects observed on a given plate. Therefore, the dimmer an object, the lower the signal-to-noise ratio (S/N) of the spectrum. This makes for an extremely inhomogeneous sample of data as far as S/N is concerned. In contrast, we observe one star at a time and adjust our exposure times to obtain spectra with a minimum S/N of approximately 50 (see Fig. 2). Thus our sample, although not as large as the SDSS, comprises data of much higher quality overall. This is key as we have shown in Gianninas, Bergeron & Fontaine (2005) the importance of high S/N for measuring the atmospheric parameters of DA white dwarfs.

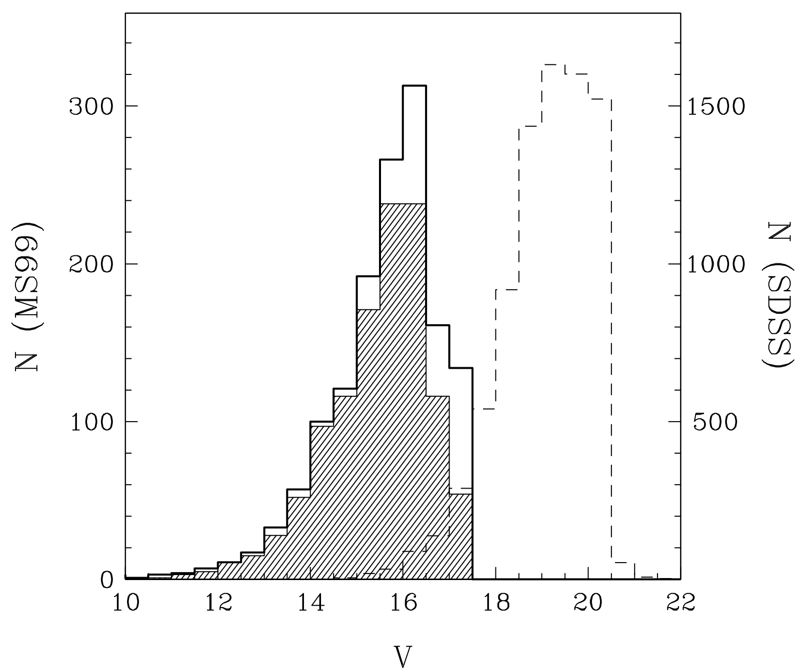

Figure 1. Distribution of visual magnitudes, V, for our sample selected from McCook & Sion (1999; *bold histogram*) and for the white dwarfs we have observed to date (*hatched histogram*). In comparison, the distribution for the SDSS sample as of Data Release 4 (Eisenstein et al. 2006) is also shown (*dashed histogram*). Note that the scale is different for the McCook & Sion sample (*left*) and the SDSS sample (*right*).

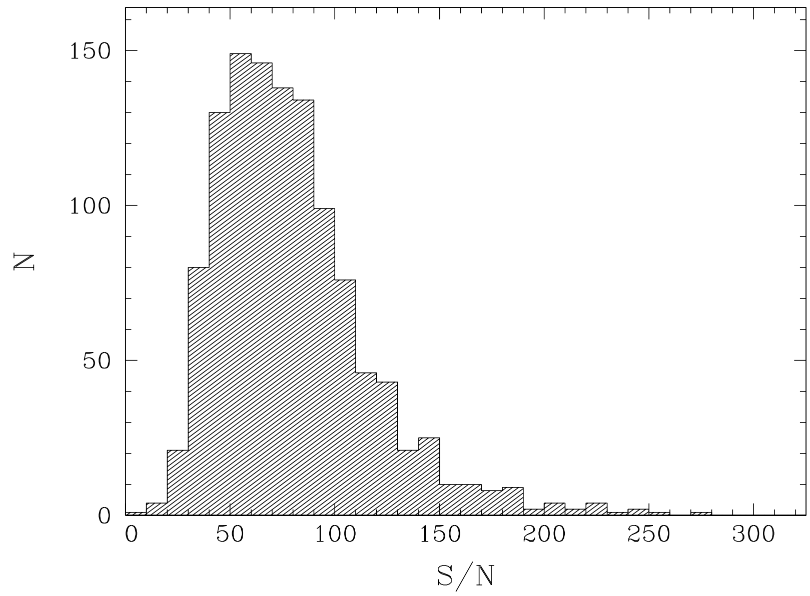

Figure 2. Distribution of S/N for the sample of DA white dwarfs for which we have obtained optical spectra. The majority of the spectra have a S/N of 50 or greater.

3. Mass distribution

We show in Figure 3 the mass distribution of our sample as a function of effective temperature. The atmospheric parameters, $T_{\rm eff}$ and $\log g$, are determined using the spectroscopic technique described in Bergeron, Saffer, & Liebert (1992; see also Liebert, Bergeron & Holberg 2005) and the masses are derived from evolutionary models with carbon/oxygen cores and thick hydrogen layers (see references in Liebert et al. 2005). Our mass distribution shows the usual increase in mass at lower temperatures as seen in the PG sample (Liebert et al. 2005), for example. This phenomenon is still not understood although many possible solutions have been proposed over the years (Bergeron, Gianninas & Boudreault 2007). We also notice a certain number of white dwarfs with masses less than $\sim$0.45 $M_\odot$. This population of low mass white dwarfs is necessarily the product of binary evolution as a progenitor with the appropriate mass could not yet have evolved to the white dwarf stage. As such, these objects are important as they represent a separate evolutionary channel for white dwarf stars.

4. DAO white dwarfs

DAO stars are hydrogen atmosphere white dwarfs whose optical spectra also contain lines of ionized helium, usually He II λ4686. The mechanism which maintains the helium in the atmosphere is still unclear, although a weak stellar wind has already been proposed. Figure 4 shows the location of the DAO stars from our sample in the $T_{\rm eff}$-$\log g$ plane along with the regular DA white dwarfs that populate that same region of the diagram. First, we notice that the sequence of DAO stars seems to be best reproduced by the 0.5 $M_\odot$ cooling track in contrast with the DA stars that follow the 0.6 $M_\odot$ cooling track, which is consistent with the accepted mean mass for white dwarfs. This can be explained if we assume that these DAO stars are the product of post-EHB evolution whereby the progenitor was not massive enough to climb back up the asymptotic giant branch (AGB) and evolved to the white dwarf stage directly from the extreme horizontal branch (EHB). We note, however, that this scenario does not apply to all DAO white dwarfs. As shown in Napiwotzki (1999), there is a sequence of DAO stars that are

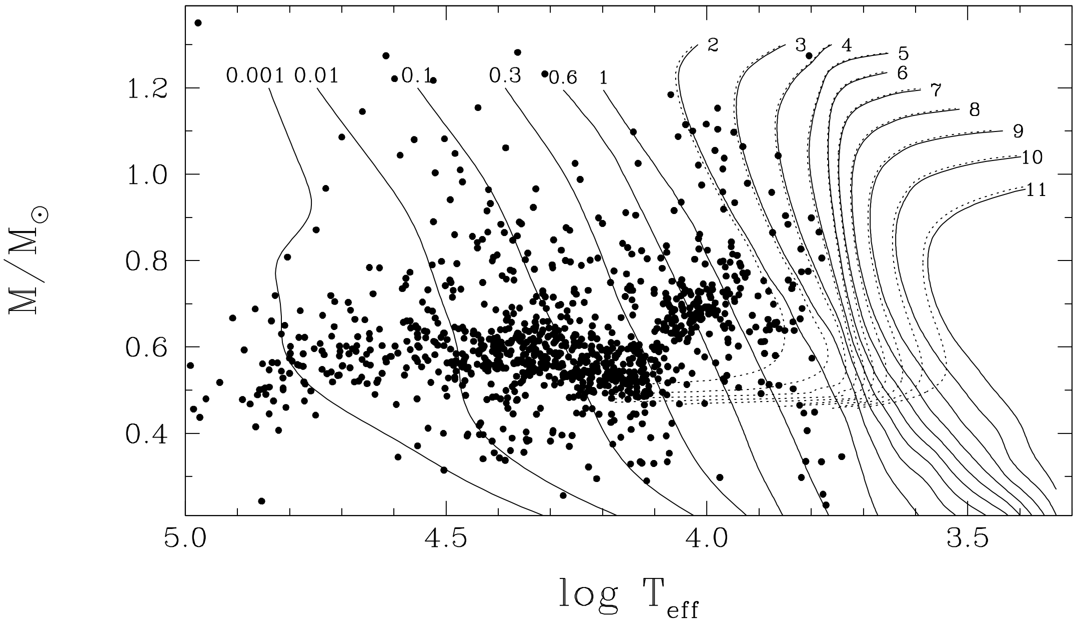

Figure 3. Mass distribution as a function of effective temperature for our entire sample. The solid lines represent isochrones which take into account only the white dwarf cooling time whereas the dotted lines include also the main sequence lifetime. Each isochrone is labeled by its age in Gyr.

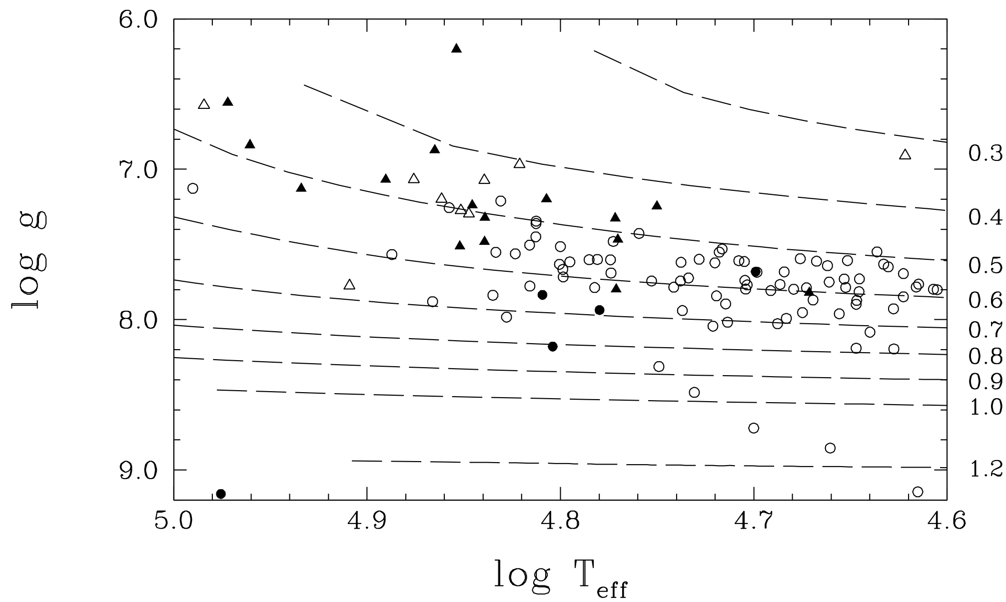

Figure 4. Section of the $\log g$ vs $\log T_{\rm eff}$ diagram showing the hot end of the DA white dwarf cooling sequence. Circles represent DA white dwarfs and triangles correspond to the DAO stars. The filled symbols indicate those stars that exhibit the Balmer line problem. The dashed lines are white dwarf cooling tracks with thick hydrogen layers and masses (in $M_\odot$) indicated to the right of the figure.

consistent with normal post-AGB evolution like the majority of white dwarfs.

We also notice in Figure 4 that most of the DAO stars exhibit the Balmer line problem as first reported by Napiwotzki (1992). The problem manifests itself as an inability to obtain consistent values of $T_{\rm eff}$ and $\log g$ from the spectroscopic fitting technique for the individual Balmer lines. Werner (1999) eventually showed that the problem could be solved by including C, N, and O in the models with proper Stark broadening of the metallic lines. We hope to include this solution within the next generation of our models in order to properly analyze these DAO white dwarfs as well as the other DA stars which exhibit the same phenomenon.

5. The ZZ Ceti instability strip

Figure 5 shows our most up to date vision of the ZZ instability strip. In particular, we have re-observed several of the variables in the strip and with the exception of one pulsator, we have spectra with S/N $\gtrsim 70$ for all our ZZ Ceti stars. However, one also notices the presence of a photometrically constant star in the middle of the instability strip, HS 1612+5528. This object had been reported as NOV (not observed to vary) by Voss et al. (2006). We obtained our own spectrum of this star and confirmed its position within the instability strip. Consequently, we decided to conduct our own observations to determine whether this star was variable or not. We observed HS 1612+5528 at the Observatoire du mont Mégantic using the Montréal three-channel photometer LAPOUNE for several hours on the night of 2006 July 20 and we detected no variations down to a limit of 0.2%. However, there are known ZZ Ceti stars that pulsate with amplitudes as low as 0.05% so we hope to obtain new high-speed photometry to determine once and for all the status of this object. For the moment, it is the only photometrically constant star contaminating the strip, but it is entirely possible that we, and Voss et al., observed HS 1612+5528 during a period of destructive interference. Alternatively, HS 1612+5528 could also represent a ZZ Ceti star whose pulsations are not detectable due to our line of sight with respect to the pulsation modes of the star.

Finally, we see that our survey as once again uncovered several new objects which lie near or within the empirical boundaries of the strip and we are exploring the possibility of obtaining high-speed photometric measurements for these stars as well.

6. DA+dM binary systems

Although the majority of stars in our survey are isolated DA white dwarfs, there are several objects whose optical spectra contain the tell-tale signs pointing to the presence of a main sequence companion, usually an M dwarf. The spectrum of the M dwarf will contaminate one or several of the Balmer lines from the white dwarf spectrum which renders our normal technique of fitting the observed Balmer line profiles very difficult. To try and get around this problem, we either exclude certain spectral lines or certain portions of the spectral lines from our fitting procedure. However, this means that our determinations of the atmospheric parameters for these stars are quite uncertain. In an effort to determine more accurately the atmospheric parameters of these white dwarfs, we have begun gathering spectra which cover the entire Balmer series from Hα to H8 thus providing sufficient wavelength coverage to determine the spectral type of the M dwarf.

Our analysis will involve a 5-parameter fit to the entire spectrum: the effective temperature and surface gravity of the white dwarf primary, the spectral type of the M dwarf secondary and the relative intensities of the two energy distributions. We will essentially be co-adding our usual synthetic spectra of DA white dwarfs with the M dwarf spectral templates from Bochanski et al. (2007). We will then use the results of the fit to subtract an appropriate template, with the proper flux level, from our initial spectrum. We see in Figure 6 a sample of some of the spectra we have obtained so far. The kink we see in the red wing of Hβ is due to a TiO band. Some spectra also show a MgH band in the blue wing of Hβ as well as Ca I between Hγ and Hδ. We

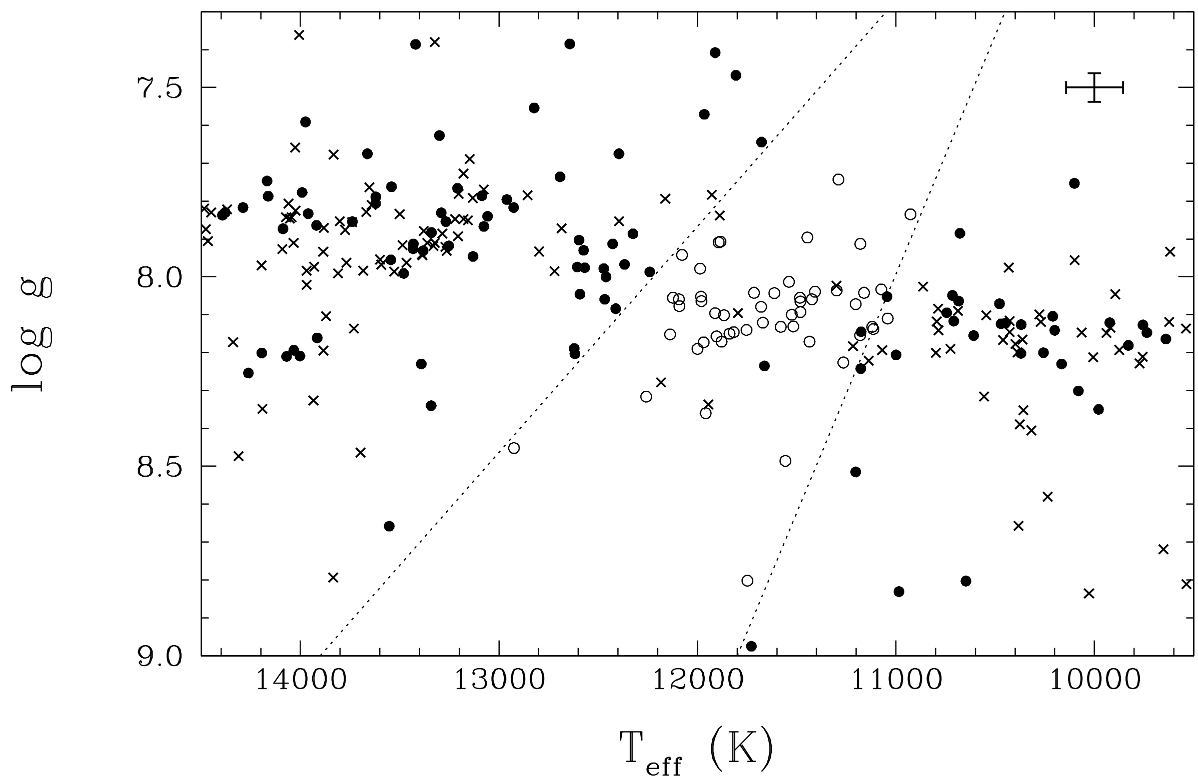

Figure 5. Section of the $\log g$ vs $T_{\rm eff}$ diagram showing the ZZ Ceti instability strip. Open circles correspond to ZZ Ceti stars while filled circles represent stars that are photometrically constant. The $\times$ symbols are stars from our survey which have never been observed for variability. The dashed lines correspond to the empirical boundaries of the instability strip and the typical error bars in this region of the $T_{\rm eff}$-$\log g$ plane are shown in the upper right corner.

also notice the prominent Na D line at 5895 Å. Furthermore, hydrogen-line emission from the M dwarf can contaminate the center of the Balmer lines of the white dwarf.

7. CBS 229

Large surveys often uncover unique and interesting objects. In the course of our survey of the DA+dM binaries described in the previous section, we came across CBS 229, an object which turned out to be rather interesting. We had initially thought that the feature in the red wing of Hβ observed in our blue spectrum (not shown here) was the usual TiO absorption band produced by the presence of an M dwarf. But our full optical spectrum, shown at the top of Figure 7, does not show any signs of an M dwarf companion. We became aware after the fact that CBS 229 had also been observed as part of SDSS, and classified as magnetic with an estimated polar magnetic field of $B_p \sim 20$ MG (Vanlandingham et al. 2005). Indeed, the SDSS spectrum (also displayed in Fig. 7) with a better spectral resolution shows what are clearly magnetic components near Hα. But the observed profile at Hβ, or even at Hα, is really at odds with the predictions of magnetic models. For instance, the models for KPD 0253+5052 shown in Figure 6 of Wickramasinghe & Ferrario (2000), with a comparable magnetic field, predict a much weaker Hα central Zeeman component with respect to the shifted components than observed in CBS 229. Furthermore, the predicted Hβ profile and the higher Balmer lines are totally smeared out, in sharp contrast with the strong and sharp Balmer lines observed in CBS 229.

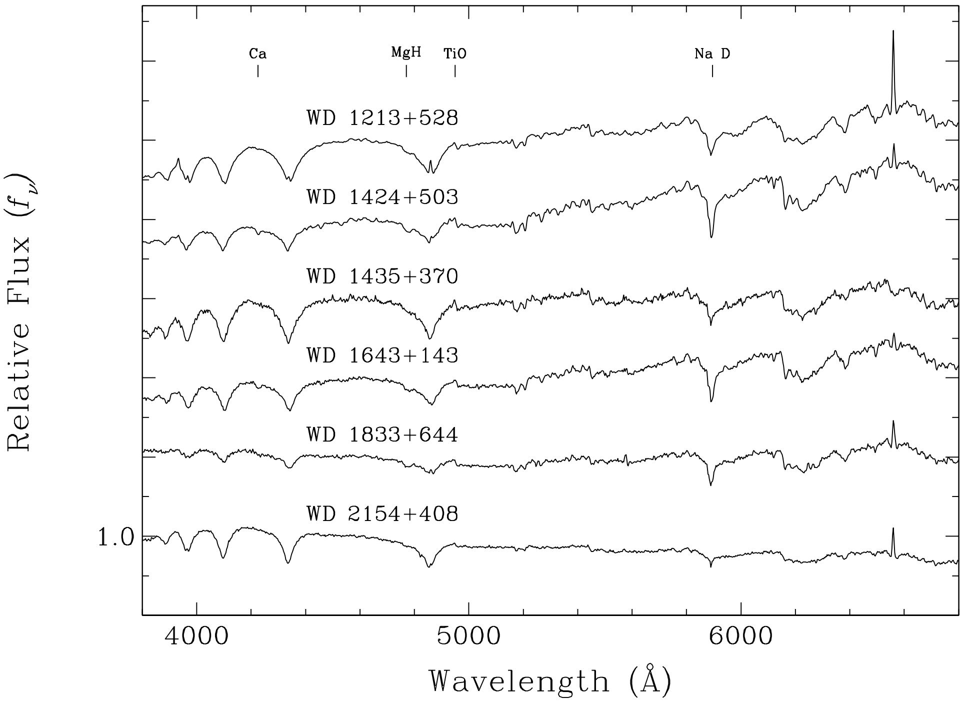

Figure 6. Optical spectra of DA+dM binary systems. Tick marks indicate metallic features in the spectrum of the M dwarf companion's spectrum.

Instead, we suggest that CBS 229 is an unresolved double degenerate binary composed of a magnetic DA star and a normal DA star. We show in Figure 7 a very preliminary attempt to deconvolve the spectrum into its two separate components. We subtracted from the SDSS data a synthetic spectrum with $T_{\rm eff} = 15,000$ K and $\log g = 8.5$. We assumed that the non-magnetic DA contributes 40% of the flux at 5500 Å; this sets the relative intensities of the spectra. The residual spectrum clearly shows magnetic features at Hα and Hβ that bear a strong resemblance with the 17 MG model shown in Figure 6 of Wickramasinghe & Ferrario (2000). To our knowledge, there are not many double degenerate systems with only one magnetic component that have been discovered and analyzed, with the exception of the LB 11146 system reported by Liebert et al. (1993), for which the companion to the non-magnetic DA white dwarf turned out to be a highly magnetic helium-atmosphere white dwarf. We plan a more detailed analysis of CBS 229 that can hopefully shed some more light on the evolution of such unique systems.

8. Future Outlook

We have several upcoming observing runs at Kitt Peak during which we hope to complete our survey of the McCook & Sion catalog in the northern hemisphere. In parallel, we will continue to obtain spectra for the remaining DA+dM binary systems that we have identified in our sample. We are also securing telescope time in Chile to complete our survey in the southern hemisphere. We hope that within a year's time our survey will essentially be complete.

Our analysis of these stars is ongoing on several fronts. We are working on adding the necessary physics in our models to analyze the DAO stars exhibiting the Balmer line problem. Our analysis of the DA+dM binaries, and in particular, our ability to extract the white dwarf spectrum will soon yield results as will our analysis of CBS 229.

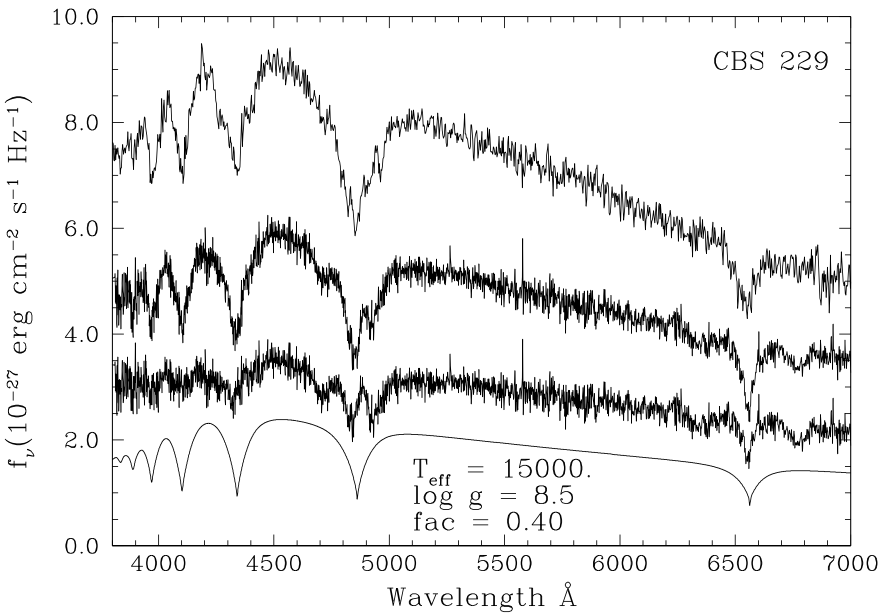

Figure 7. Our own spectrum (first from the top) and the SDSS spectrum (second from the top) of CBS 229. At the bottom, a synthetic spectrum of a DA white dwarf corresponding to the atmospheric parameters indicated in the figure. The quantity $fac = 0.40$ implies that the synthetic spectrum contributes 40% of the flux of the sytem at 5500 Å. The spectrum just above is the residual left over from subtracting the synthetic DA model from the SDSS spectrum.

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